PASSIVE CROSSOVERS

Passive crossovers are one of those voodoos that are often misunderstood and incorrectly applied in car audio. Before we proceed any further into this subject, it is important to discuss the difficulty in properly designing passive crossovers.

The design and implementation of passive crossovers is as much an art, as it is a science. Although a working knowledge of AC theory and computer measuring and modeling programs help; experience is as much, if not more important.

Engineers start their crossover designs by measuring the frequency responce, phase responce and impedance of the speakers. They also often use computer modeling programs that will import this data and model the affects of different crossover components and circuits on the imported data.

Passive crossovers will affect the speaker systems power responce (on and off axis frequency responce) impedance and phase. Predicting these affects can often times be very difficult.

The use of "cookbook" type passive crossovers by inexperienced individuals may lead to unsatisfactory electrical (very extreme impedance and/or reactance shutting down your amp) and audible (awful sounding) results.

The following information is presented as a simple lesson and starting point in the basics of passive crossover design. It describes the basic components and circuit topologies used in crossover design and their affects on a speaker system. Crossover charts using "cookbook" component values are also included, but only as a starting basis of crossover design.

It is important to keep in mind that "cookbook" component values are calculated using a resistor as the load. Everything changes once we switch the load from a resistor to a speaker. A speaker has a reactive impedance (changes with frequency) where as a resistor only has DC resistance (does not change with frequency).

PLEASE PROCEED WITH CAUTION!

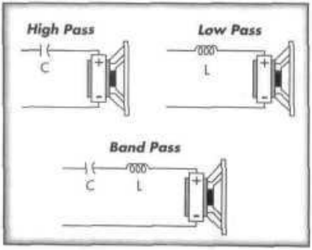
The Components

When describing the crossover types it is important to understand what effects capacitors and inductors have at audio frequencies. The Capacitor (C) is a device in which the Capacitive Reactance (XC) increases with decreasing frequency. This means that as the frequency goes down the resistance to the signal goes up, giving us a high pass device. The Inductor (L) is a device in which Inductive Reactance (XL) increases with increasing frequency. This means that as the frequency goes up the resistance to the signal goes up, giving us a low pass device. What this means is they work together as frequency dependent attenuators. It is also important to note that these devices have the ability to store energy, thus affecting phase as well as frequency. Resistors are also used in crossovers to "tune" certain capacitor and inductor branches, or to attenuate a complete network of a passive crossover.

FILTER TYPES

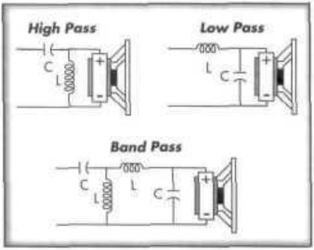
1ST ORDER

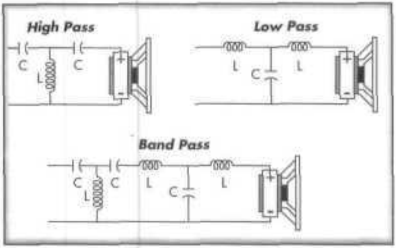
A first order crossover is one that causes the energy to the driver to roll off at 6db per octave beyond the cut-off frequency. This type usually has one component in each of it's networks or two components in a band pass network. These networks cause a +45 degree phase shift in the high pass section and a -45 degree phase shift in the low pass section for a combined 90 degree phase shift at the cut off frequency. These crossover types are easy to design and offer good phase response. On the other hand because of there gradual roll offs, the drivers must have smooth natural roll offs or there abnormalities will be heard. 1st order networks are also critically dependent on there listening axis due to the broad overlap of the drivers response. This is important to there frequency response in a car.



2ND ORDER

A second order crossover is one that causes the energy to the driver to roll off at 12 dB per octave beyond the cut off frequency. This type usually combines a capacitor and inductor in the network. A series cap and parallel Inductor for high pass and a series inductor and parallel capacitor for low pass. The band pass network will combine the two networks resulting in four components. These networks cause a +90 degree phase shift for the high pass and a -90 degree phase shift for the low pass. This results in a 180 degree phase shift at the cut off frequency. This may cause the speakers to be out of phase at the cut off frequency. Reversing one of the speaker leads will result in the response being back in phase at the cut off frequency, but 180 degree out of phase every where else in the crossover region. Experimentation is valuable in these cases.



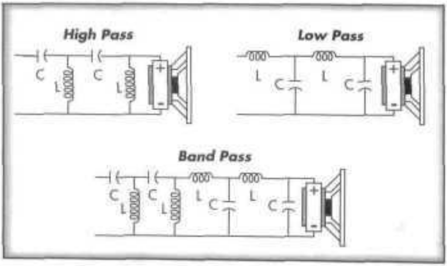


3RD ORDER

A 3rd order crossover is one that causes the energy to the driver to roll off at 18 dB per octave beyond the cut off frequency. These types combine 3 components in series and parallel and 6 components for bandpass. Unlike the 1st and 2nd order filters in which the cap and inductor remain the same value for low pass and high pass, the 3rd order changes values for a high pass and low pass at the same frequency. These networks cause a +135 degree phase shift for the high pass and a -135 degree phase shift for the low pass. This results in a 270 degree phase shift at the cut off frequency.

4TH ORDER

A 4th order crossover is one that causes the energy to the driver to roll off at 24 dB per octave beyond the cut off frequency. This type combines four components in series and parallel for the high pass or low pass sections and eight components for a band pass network. Like the 3rd order crossover this type uses different values for the high pass and low pass filters. These networks cause a +180 degree phase shift for the high pass and -180 degree phase shift for the low pass. This results in a 360 degree phase shift at the cut off frequency. This means that one driver is a complete wave length behind the other but in phase.



RESPONSE AND IMPEDANCE CORRECTIONS

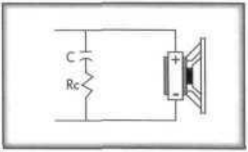
Impedance Problems

For crossovers to function properly they must drive a constant impedance throughout the crossover band. Drivers in there "reactive" nature possess anything but a constant impedance, because of resonances, voice coil motor and inductance, radical impedance changes are prevalent. By using special circuits to cancel these impedance variations we can maintain a constant impedance for our crossovers to work with. Using these two circuits will make this job easier. Note: You will need the speakers T/S parameters for the following formulas.

Impedance Equalizers (Zobel)

By using this circuit the impedance rise of a speaker can be "flattened". Use these formulas to calculate the values for C & Rc:

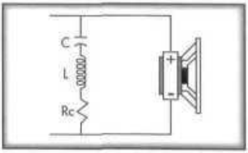
$$Rc = 1.25 \times Re$$
$$C = Le/Rc^2$$



Series Notch Filter

Buy using this circuit we can dampen or eliminate a drivers resonance effect on a crossover. This is critical if the drivers resonance (Fs) is less than 2 octaves away from the cut off frequency of the crossovers.

$$C = 0.1592/(Re \times Qes \times Fs)$$
$$L = 0.1592\ (Qes \times Re)/Fs$$
$$Rc = Re + (Qes \times Re)/Qms$$

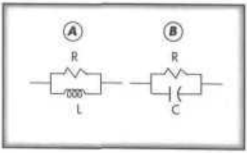


Shaping Circuits

Sometimes a speaker's frequency response has inherent problems. We can use several types of circuits to correct them. The following circuits are designed to tailor driver response by contouring or trapping certain frequencies.

Contour Networks

Contour networks use a simple resistor and inductor or resistor and capacitor circuit to modify rising frequency response tendencies. Use circuit A when response is rising with increasing frequency. Use circuit B when response is rising with decreasing frequency. Use the following formulas for both circuits:



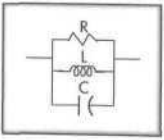
Ⓐ $C = 0.15916/f$ (frequency at which response rise starts)
Ⓑ $L = 0.15916/f$ (frequency at which response rise starts)

Finding the value for R is a complicated process which entails measuring reactance at several frequencies and then using decibel formulas to calculate R for a given attenuation. Without giving you pages of algebra to do this would be a difficult procedure. Using your RTA and your ears to tune R is much faster and easier. Use resistors between 4 to 20 Ohm for a starting point.

Trap or Notch Networks

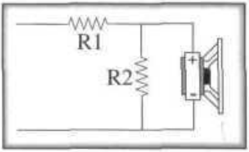
Notch circuits use a resistor, inductor and a capacitor circuits to remove broad peaks in a driver's frequency response. To use this circuit we must find f (frequency where peak exists), f1 (the -3dB point lower than f) and f2 (the -3dB point higher than f). Then use these formulas to calculate the inductor, capacitor and resistor values:

$$C = 0.03002/f$$
$$L = 0.02252/(f2 \times C)$$
$$R = 1/6.28 \times C \times (f1 - f2)$$



ATTENUATION CIRCUIT FOR PASSIVE CROSSOVERS

When designing passive crossovers, there will be times when the drivers output levels will not acoustically match-up. This may be due to the efficiency differences in the drivers; or the positioning of the drivers and the distance between them acts as an attenuator. By utilizing a L-Pad network, you can electrically "pad" the output of a driver so that all of the levels match up. Determine the amount of attenuation needed and then look up the the resistor values to use on the following chart.



Attenuation Amount	2Ω R1	2Ω R2	4Ω R1	4Ω R2	8Ω R1	8Ω R2
-3dB	0.5Ω@10W	4.7Ω@10W	1.2Ω@15W	10Ω@10W	2.4Ω@15W	20Ω@10W
-6dB	1.0Ω@25W	2.0Ω@15W	2.0Ω@25W	3.9Ω@15W	3.9Ω@25W	8.2Ω@15W
-9dB	1.3Ω@25W	1.1Ω@10W	2.7Ω@25W	2.2Ω@10W	5.1Ω@25W	4.3Ω@10W
-12dB	1.5Ω@25W	0.7Ω@10W	3.0Ω@25W	1.3Ω@10W	6.2Ω@25W	2.7Ω@10W
-15dB	1.6Ω@50W	0.5Ω@10W	3.3Ω@50W	0.8Ω@10W	6.8Ω@50W	1.8Ω@10W
-18dB	1.8Ω@50W	0.3Ω@5W	3.6Ω@50W	0.5Ω@5W	7.5Ω@50W	1.2Ω@5W

* **Note**: Resister power ratings are recommended values only. These values are based on an average 50 Watt input power and higher values should be used when the input power is higher than 50Watts.

COIL MEASUREMENT AND LINEARITY

Coil values are measured in millihenries (mH) which is the inductance of of a coil. The greater the inductance, the lower the crossover frequency of the coil. Air coils remain linear (do not change inductance) at high power. All of our ratings take into account coil linearity.

Series and Parallel Coils

When coils are in series, their values (mH) are added. Parallel coils create a lesser value combination. Use the following equations to calculate the total inductance.

$$L_{T(series)} = L_1 + L_2 + L_3$$

$$L_{T(parallel)} = \frac{1}{\frac{1}{L_1} + \frac{1}{L_2} + \frac{1}{L_3}}$$

Parallel and Series Capacitors

There may be occasions when the value (µF) of a capacitor needed for a particular crossover point is not available. Capacitors in Parallel add to equal the total of their values. Series capacitors create a lesser value combination. Use the following equations to calculate the total capacitance.

$$C_{T(parallel)} = C_1 + C_2 + C_3$$

$$C_{T(series)} = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}}$$

APPLYING WHAT WE HAVE LEARNED

It is important to remember the information above is only the basics, and a reference for passive crossover design. Implementing some of this theory and "cookbook" component values should only be used as a starting point. The following is a simplified method of applying some of the theory and "cookbook" values to acheive desirable results. Keep in mind that the best tools for optimizing the results are your ears and an RTA.

Start by determining the crossover points by studying the drivers frequency/phase response and impedance. If the manufacturer can not provide these, the driver is probably not worth using! Remember that the electrical response of your network will work in conjunction with the drivers natural roll off. This means that if your driver has a 6dB per octave acoustical roll off and you add a 12dB per octave electrical network to it, the driver will exhibit an 18dB per octave acoustical roll off characteristic. Once you have determined the network you wish to use, look at the following "Cook Book" crossover charts for the starting values needed to build the crossover. Using the parameters for the drivers, calculate the impedance circuits for all the speakers. Usually tweeters and subwoofers are not as susceptible to impedance problems. Tweeters will tend to have a shallow voice coil inductance rise and subwoofers are typically never used in the region where rises in impedance are critical. Using shaped circuits, equalize any problems that the drivers may have in their frequency response.

Remember that 1st order networks are not always the best choice. If you do choose to use them make sure the driver has a smooth natural roll off. 1st order networks also exhibit directional power response characteristics and can be "beamy" at certain frequencies. This can be used to help with imaging, or it can destroy it as well. Always use the best capacitors you can!! Polypropylene or mylar film caps are best for audio frequencies. Coils should be chosen according to their application. Iron coils feature very low DCR's (series resistance) but can saturate and distort with high current conditions. Air core coils have higher DCR's but do not saturate as quickly with high current conditions. When using resistors make sure you use large enough power ratings to withstand the current of your amp. If you use 25Watt resistors you usually will be safe.

It is important to remember that drivers do not act as constant resistive loads. This causes a lot of problems in crossover design. Acoustic Engineers use exotic electro-acoustic programs and sophisticated measurement systems to optimize crossovers. These programs can take hours to optimize (that's a lot of math). Days of optimizing and listening tests can occur for a single two way crossover design. Keep in mind that "Cookbook" crossover charts are used with resistive loads. Drivers are not resistive loads! The following filter charts all exhibit Butterworth (flat with Q=0.7) type responses. Remember to use the right steps and let your ears do the final tuning. Practice makes perfect.

PASSIVE CROSSOVER CHART

2 OHM LOAD

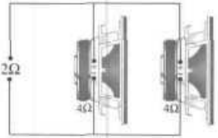
Freq. (Hz)	6dB Coil (mH)	6dB Cap (µF)	12dB Coil (mH)	12dB Cap (µF)	18dB LP Coil (mH)	18dB LP Cap (µF)	18dB LP Coil (mH)	18dB HP Cap (µF)	18dB HP Coil (mH)	18dB HP Cap (µF)
50	6.4	1592	9.0	1125	9.6	2117	3.2	1062	4.8	3178
60	5.3	1326	7.5	938	8.0	1764	2.7	885	4.0	2648
70	4.6	1137	6.4	804	6.8	1512	2.3	758	3.4	2270
80	4.0	995	5.6	703	6.0	1323	2.0	664	3.0	1986
85	3.7	936	5.3	662	5.6	1245	1.9	625	2.8	1870
90	3.6	884	5.0	625	5.3	1176	1.8	590	2.7	1766
95	3.4	838	4.7	592	5.0	1114	1.7	559	2.5	1673
100	3.2	796	4.5	563	4.8	1058	1.6	531	2.4	1589
120	2.7	663	3.7	469	4.0	882	1.3	442	2.0	1324
125	2.5	637	3.6	450	3.8	847	1.3	425	1.9	1271
150	2.1	531	3.0	375	3.2	706	1.1	354	1.6	1059
170	1.8	468	2.7	331	2.8	623	1.0	312	1.4	935
200	1.6	398	2.3	281	2.4	529	.8	265	1.2	795
225	1.4	354	2.0	250	2.1	470	.7	236	1.1	706
250	1.3	318	1.8	225	1.9	423	.6	212	1.0	636
275	1.2	289	1.6	205	1.7	385	.6	193	.9	578
300	1.1	265	1.5	188	1.6	353	.5	177	.8	530
400	.8	199	1.1	141	1.2	265	4	133	6	397
500	.7	159	.9	113	.95	212	.3	106	.5	318
600	.5	133	.8	94	.8	176	.3	89	.4	265
800	.4	99	.6	70	.6	132	.2	66	.3	199
1000	.3	80	.5	56	.5	106	.2	53	.3	159
1500	.2	53	.3	38	.3	70	.1	35	.2	106
2000	.2	40	.2	28	.3	53	.08	27	.1	80
2500	.1	32	.2	23	.2	42	.06	21	.1	64
3000	.1	27	.2	19	.2	35	.05	18	.08	53
3500	.1	23	.1	16	.1	30	.05	15	.07	45
4000	.08	20	.1	14	.1	27	.04	13	.06	40
4500	.07	18	.1	13	.1	24	.04	12	.05	35
5000	.06	16	.09	11	.1	21	.03	11	.05	32
5500	.06	15	.08	10	.09	19	.03	9.7	.04	29
6000	.05	13	.08	9.4	.08	18	.03	8.8	.04	27
6500	.05	12	.07	8.8	.07	16	.02	8.2	.04	24
7000	.05	11	.06	8	.07	15	.02	706	.03	23
8000	.04	9.9	.06	7	.06	13	.02	6.6	.03	20
9000	.04	8.8	.05	6.3	.05	12	.02	5.9	.03	18
10000	.03	8	.05	5.6	.05	11	.02	5.3	.02	16

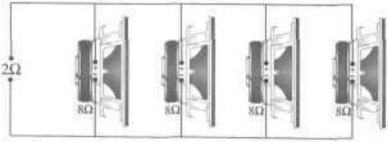
Phoenix Gold
ACOUSTICS

PASSIVE CROSSOVER CHART

24dB/OCTAVE, 2 OHM LOAD

Freq. (Hz)	HIGH PASS Cap (µH)	Coil (mH)	Cap (µH)	Coil (mH)	LOWPASS Coil (mH)	Cap (µH)	Coil (mH)	Cap (µH)
100	520	2.0	735	8.0	5.0	1254	3.5	305
125	416	1.5	588	7.0	4.0	1003	2.8	244
150	347	1.3	490	5.5	3.0	836	2.3	203
175	297	1.3	420	4.5	2.8	717	2.0	174
200	260	1.0	368	4.0	2.5	627	1.8	152
250	208	0.8	294	3.5	2.0	502	1.5	122
300	173	0.7	245	2.8	1.8	418	1.0	102
350	149	0.6	210	2.5	1.5	358	1.0	87
400	130	0.5	184	2.0	1.3	314	0.9	76
500	104	0.4	147	1.7	1.0	251	0.7	61
600	87	0.4	123	1.5	0.8	209	0.6	51
700	74	0.3	105	1.3	0.7	179	0.5	44
800	65	0.3	92	1.0	0.6	157	0.4	38
1000	52	0.2	74	0.8	0.5	125	0.4	30
1500	35	0.2	49	0.5	0.3	84	0.3	20
2000	26	0.1	37	0.4	0.3	63	0.2	15
2500	21	0.05	29	0.4	0.2	50	0.2	12
3000	17	0.05	25	0.3	0.2	42	0.1	10
3500	15	0.05	21	0.3	0.2	36	0.1	8.7
4000	13	0.05	18	0.2	0.1	31	0.1	7.5
4500	11	0.04	16	0.2	0.1	28	0.07	6.7
5000	10	0.04	15	0.15	0.1	25	0.05	6.0
6000	8.6	0.03	12	0.14	0.08	21	0.05	5.0





PHOENIX GOLD
ACOUSTICS

PASSIVE CROSSOVER CHART

4 OHM LOAD

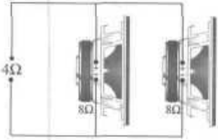
Freq. (Hz)	6dB Coil (mH)	6dB Cap (μF)	12dB Coil (mH)	12dB Cap (μF)	18dB LP Coil (mH)	18dB LP Cap (μF)	18dB LP Coil (mH)	18dB HP Cap (μF)	18dB HP Coil (mH)	18dB HP Cap (μF)
50	12.8	796	18.0	563	19.1	1058	6.4	531	9.6	1589
60	10.6	663	15.0	468	15.9	882	5.3	442	8.0	1324
70	9.0	568	12.8	402	13.6	756	4.5	379	6.8	1135
80	8.0	497	11.3	352	12.0	662	4.0	331	6.0	993
85	7.5	468	10.6	331	11.2	623	3.8	312	5.6	935
90	7.2	442	10.0	313	10.6	588	3.6	295	5.3	883
95	6.7	419	9.5	296	10.0	557	3.4	279	5.0	836
100	6.4	398	9.0	281	9.6	529	3.2	265	4.8	795
120	5.3	331	7.5	234	8.0	441	2.7	221	4.0	662
125	5.1	318	7.2	225	7.6	423	2.5	212	3.8	636
150	4.2	265	6.0	188	6.4	353	2.1	177	3.2	530
170	3.7	234	5.3	165	5.6	311	1.9	156	2.8	467
200	3.2	199	4.5	141	4.8	265	1.6	133	2.4	398
25	2.8	177	4.0	125	4.2	234	1.4	118	2.1	353
250	2.5	159	3.6	113	3.8	212	1.3	106	1.9	318
275	2.3	145	3.2	102	3.5	192	1.2	97	1.7	289
300	2.1	133	3.0	94	3.2	176	1.1	89	1.6	265
400	1.6	99	2.3	70	2.4	133	.8	66	1.2	199
500	1.3	80	1.8	56	1.9	106	.7	53	1.0	159
600	1.1	66	1.5	47	1.6	88	.5	44	.8	133
800	.8	50	1.2	35	1.2	66	.4	33	.6	99
1000	.7	40	.9	28	1.0	53	.3	27	.5	80
1500	.4	27	.6	19	.7	35	.2	18	.3	53
2000	.3	20	.5	14	.5	27	.2	13	.2	40
2500	.3	16	.4	11	.4	21	.2	11	.2	32
3000	.2	13	.3	9.4	.4	18	.1	8.8	.2	27
3500	.2	11	.3	8	.3	15	.1	7.6	.1	23
4000	.2	9.9	.2	7	.3	13	.08	6.6	.1	20
4500	.1	8.8	.2	6.3	.3	12	.07	5.9	.1	18
5000	.1	8.0	.2	5.6	.2	11	.06	5.3	.1	16
5500	.1	7.2	.2	5.1	.2	9.6	.06	4.8	.09	14
6000	.1	6.6	.2	4.7	.2	8.8	.05	4.4	.08	13
6500	.1	6.1	.1	4.3	.2	8.1	.05	4.1	.07	12
7000	.09	5.6	.1	4	.1	7.6	.05	3.8	.07	11
8000	.08	5	.1	3.5	.1	6.6	.04	3.3	.06	9.9
9000	.07	4.4	.1	3.1	.1	5.9	.04	2.9	.05	8.8
10000	.06	4	.09	2.8	.1	5.3	.03	2.7	.05	8

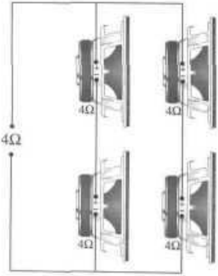
PHOENIX GOLD
ACOUSTICS

PASSIVE CROSSOVER CHART

24dB/OCTAVE, 4 OHM LOAD

	HIGH PASS				LOWPASS			
Freq. (Hz)	Cap (µH)	Coil (mH)	Cap (µH)	Coil (mH)	Coil (mH)	Cap (µH)	Coil (mH)	Cap (µH)
100	260	4.0	367	16.6	9.75	627	7.0	152
125	208	3.2	294	13.3	7.8	501	5.5	122
150	173	2.7	245	11	6.5	418	4.5	101
175	149	2.3	210	9.5	5.5	358	4.0	87
200	130	2.0	184	8.3	4.9	314	3.5	76
250	104	1.6	147	6.6	3.9	251	2.8	61
300	87	1.3	122	5.5	3.3	210	2.3	50
350	74	1.2	105	4.7	2.8	180	2.0	44
400	65	1.0	92	4.2	2.5	157	1.7	38
500	52	0.8	74	3.3	2.0	126	1.4	30
600	43	0.7	61	2.8	1.6	105	1.2	25
700	37	0.6	53	2.4	1.4	89	0.9	22
800	33	0.5	46	2.0	1.2	78	0.8	19
1000	26	0.4	37	1.7	1.0	63	0.7	15
1500	17	0.3	25	1.1	0.7	42	0.5	10
2000	13	0.2	18	0.8	0.5	31	0.4	8
2500	10	0.2	15	0.7	0.4	25	0.3	6
3000	9	0.1	12	0.5	0.3	21	0.2	5
3500	7	0.1	11	0.4	0.3	18	0.2	4
4000	6	0.1	9	0.4	0.2	16	0.2	4
4500	5	0.1	8	0.4	0.2	14	0.2	3
5000	5	0.1	7	0.3	0.2	13	0.1	3
6000	4	0.1	6	0.3	0.2	11	0.1	2



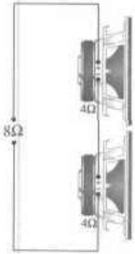


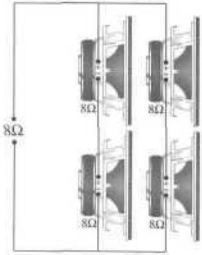
PHOENIX GOLD
ACOUSTICS

PASSIVE CROSSOVER CHART

24dB/OCTAVE, 8 OHM LOAD

Freq. (Hz)	HIGH PASS Cap (µH)	Coil (mH)	Cap (µH)	Coil (mH)	LOWPASS Coil (mH)	Cap (µH)	Coil (mH)	Cap (µH)
100	130	8.0	184	33	19.5	313	14	76
125	104	6.5	147	27	15.5	251	11	61
150	87	5.3	123	22	13	209	9.2	51
175	75	4.6	105	19	11	179	8	44
200	65	4.0	92	16.6	9.7	157	6.9	68
250	52	3.2	74	13.0	7.8	125	5.5	30
300	43	2.7	61	11	6.5	104	4.6	25
350	37	2.3	153	9.5	5.6	90	3.9	22
400	33	2.0	46	8.3	4.9	78	3.5	19
500	26	1.6	37	6.6	3.9	63	2.8	15
600	22	1.4	30	5.5	3.3	52	2.3	13
700	19	1.2	26	4.8	2.8	45	2.0	11
800	16	1.0	23	4.2	2.4	40	1.7	9
1000	13	0.8	18	3.3	2.0	32	1.4	7.6
1500	9	0.5	12	2.2	1.3	21	0.9	5
2000	7	0.4	9	1.6	1.0	16	0.7	4
2500	5	0.3	7	1.3	0.8	13	0.5	3
3000	4	0.3	6	1	0.7	10	0.5	3
3500	4	0.2	5	0.9	0.5	9	0.4	2
4000	3	0.2	4	0.8	0.5	8	0.35	2
4500	3	0.2	4	0.7	0.4	7	0.3	2
5000	2	0.2	3	0.6	0.4	6	0.3	1
6000	2	0.1	3	0.5	0.33	5	0.25	1





PHOENIX GOLD
ACOUSTICS